

EXHIBIT D



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(54) **AGENT REACTIVE SCHEDULING IN AN AUTOMATED MANUFACTURING ENVIRONMENT**

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Related U.S. Application Data

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(51) Int. Cl.⁷ **G06F 19/00**

(52) U.S. Cl. **700/99; 700/100; 700/121;**
705/8

(58) Field of Search 700/99, 100, 101,
700/117, 121; 705/8

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,994,980 A * 2/1991 Lee et al. 700/173

5,696,689 A * 12/1997 Okumura et al. 700/121
5,943,652 A * 8/1999 Sisley et al. 705/9

OTHER PUBLICATIONS

"A Dynamic Reactive Scheduling Mechanism for Responding to Changes of Production Orders and Manufacturing Resources", 2001, Elsevier Science.

* cited by examiner

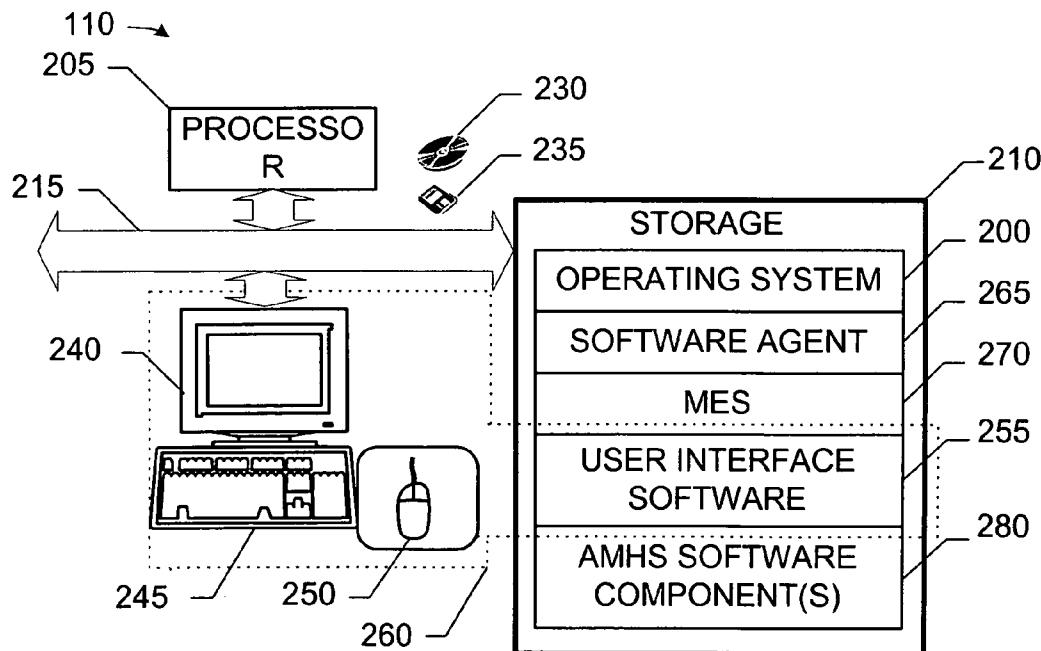
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(57) **ABSTRACT**

A method and apparatus for scheduling in an automated manufacturing environment, comprising are disclosed. The method includes detecting an occurrence of a predetermined event in a process flow; notifying a software scheduling agent of the occurrence; and reactively scheduling an action from the software scheduling agent responsive to the detection of the predetermined event. The apparatus is automated manufacturing environment including a process flow and a computing system. The computing system further includes a plurality of software scheduling agents residing thereon, the software scheduling agents being capable of reactively scheduling appointments for activities in the process flow responsive to a plurality of predetermined events.

22 Claims, 6 Drawing Sheets

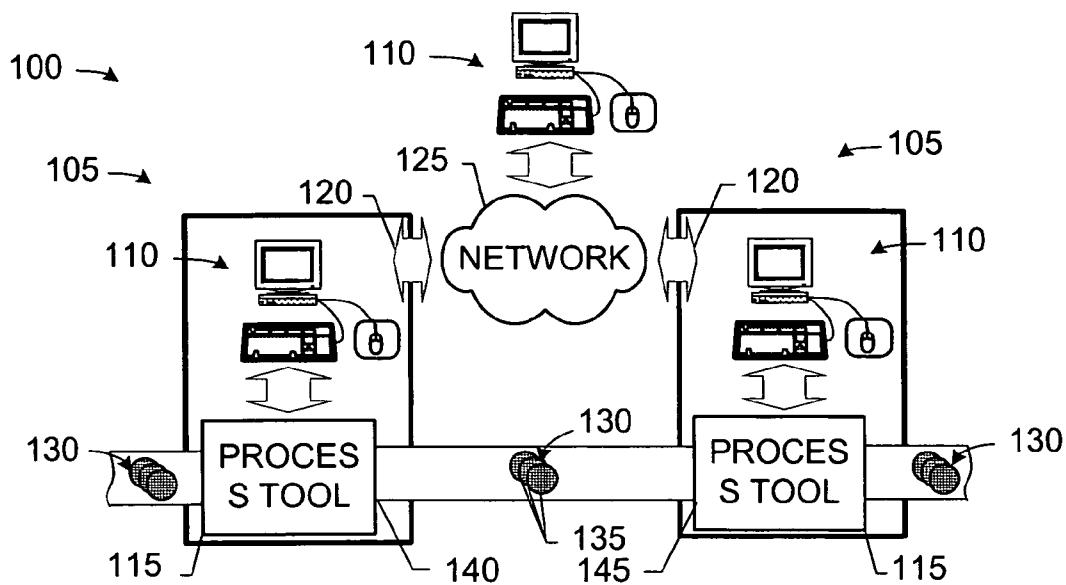
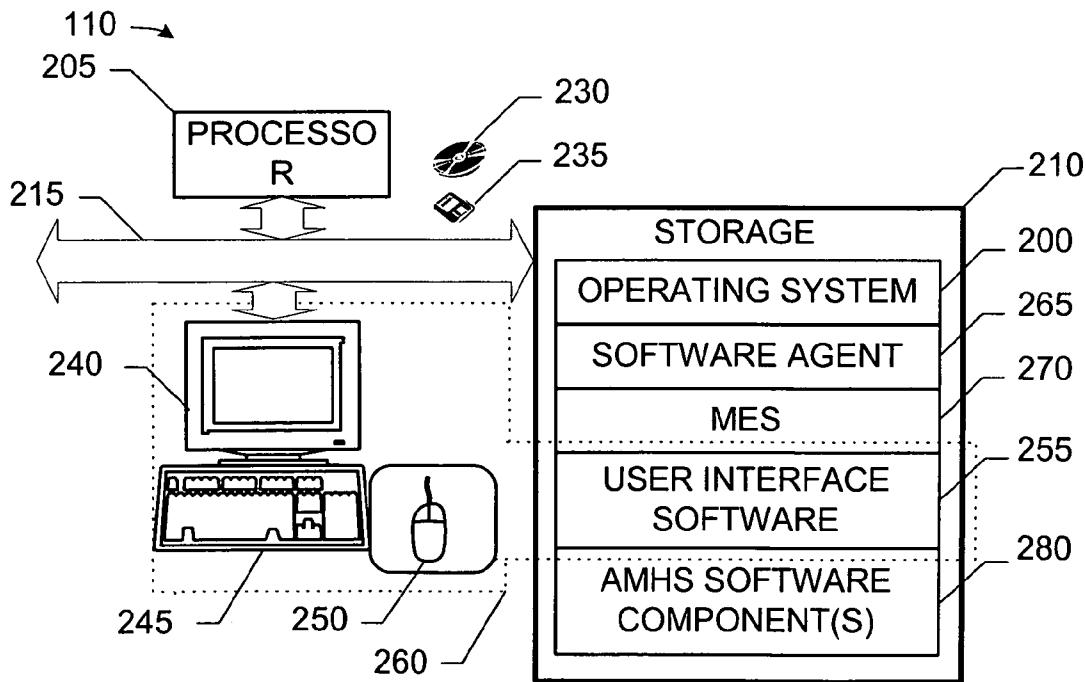


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**FIG. 1****FIG. 2**

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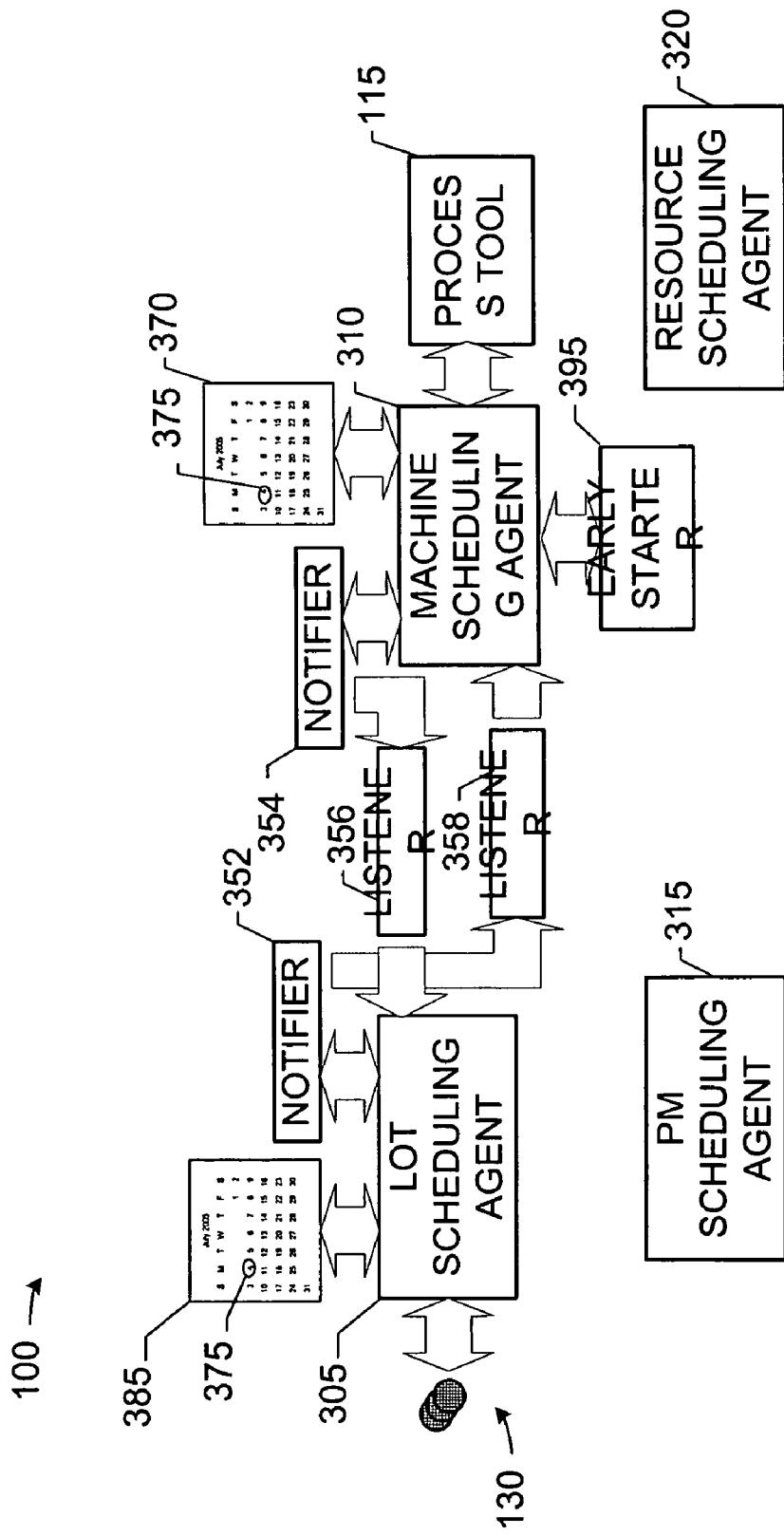


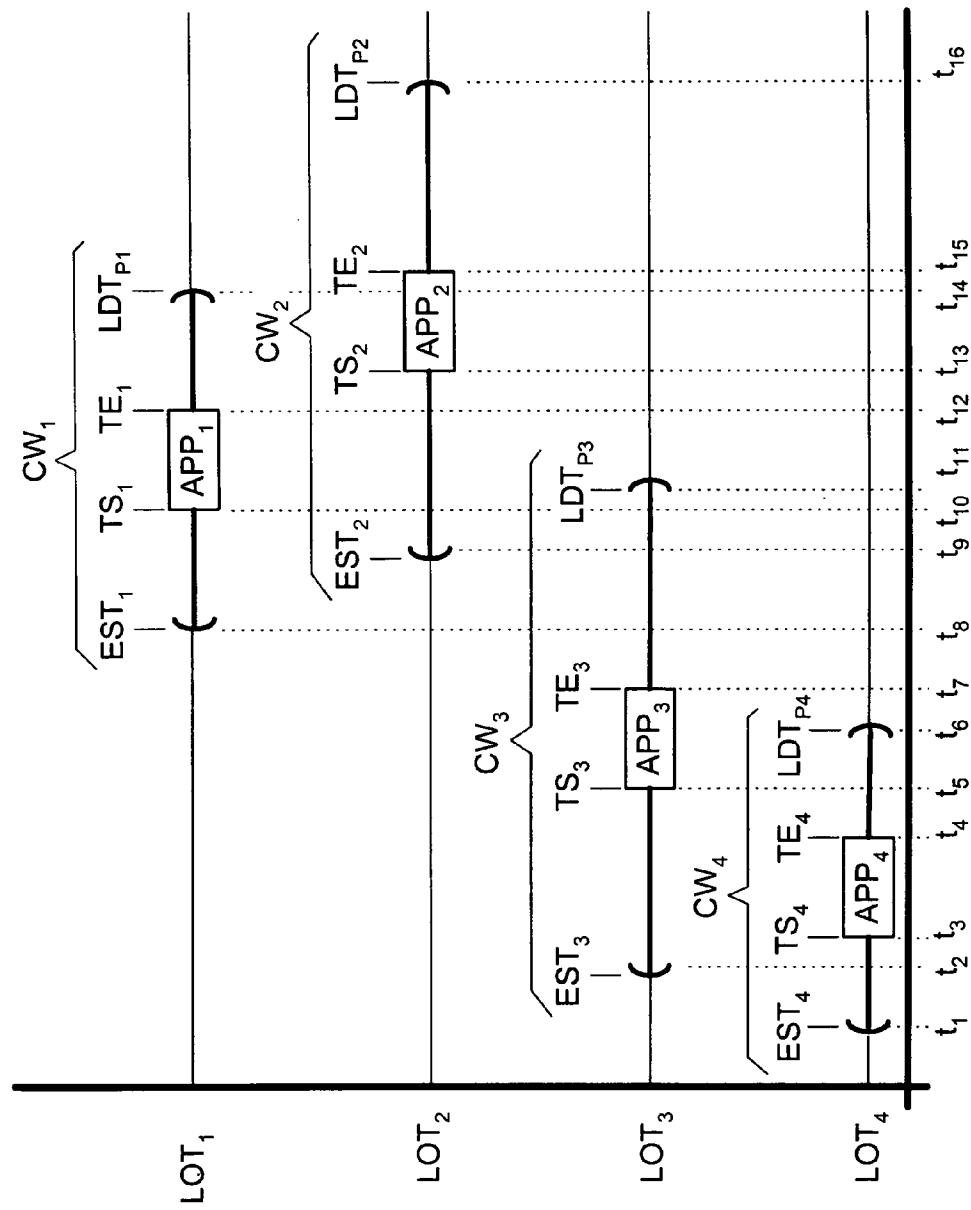
FIG. 3

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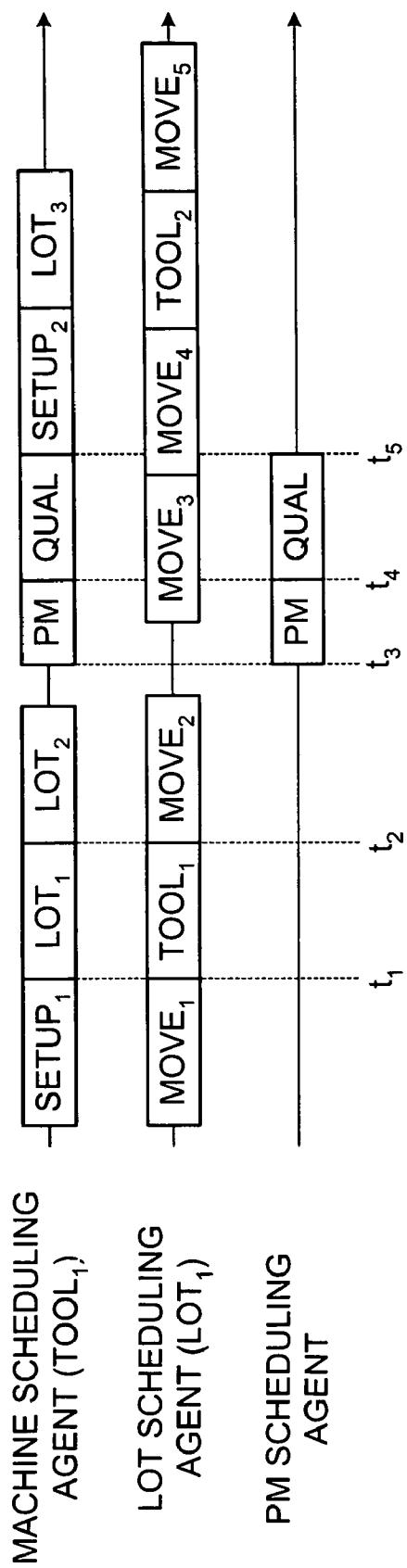
**FIG. 4**

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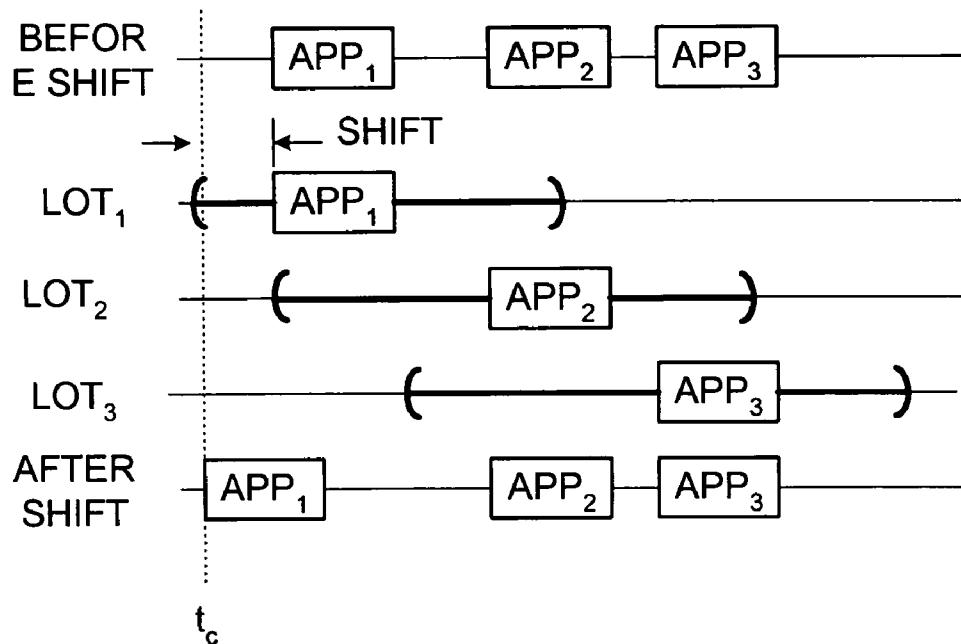
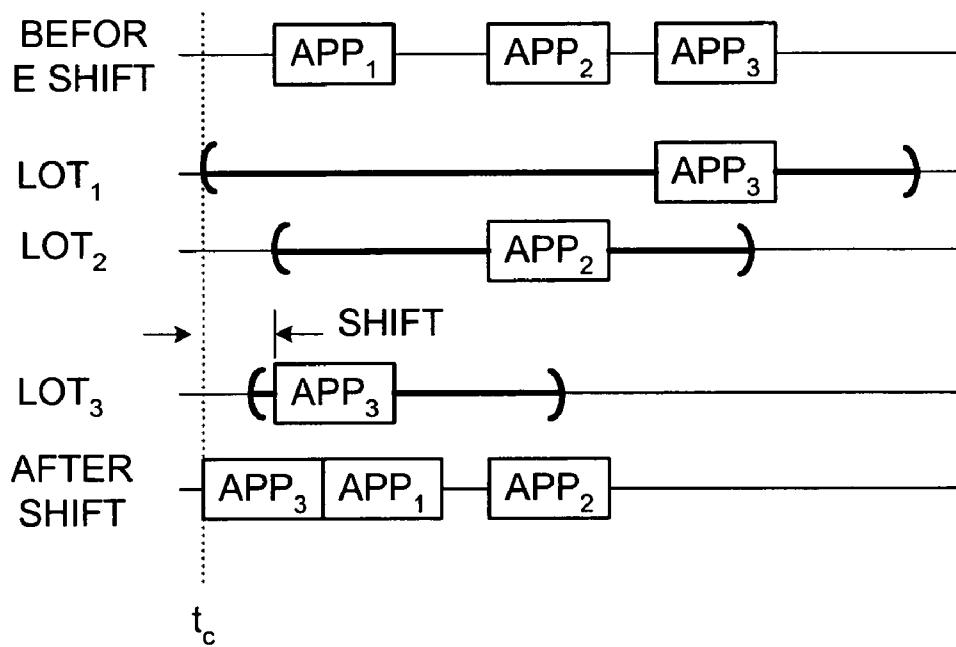
**FIG. 5**

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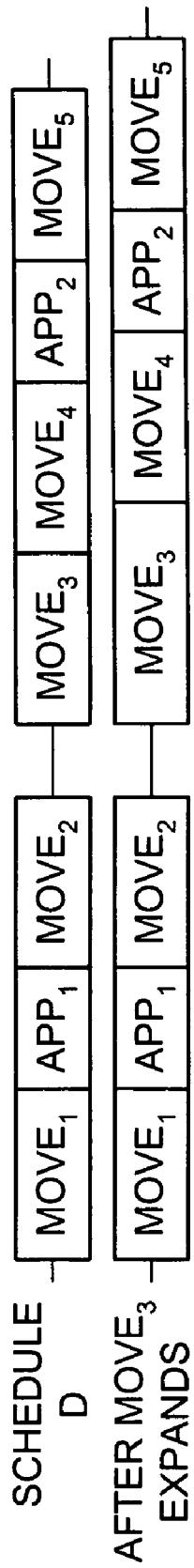
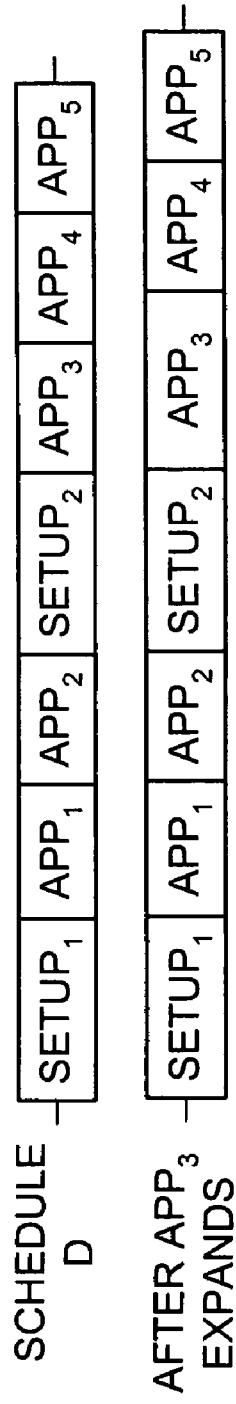
**FIG. 6A****FIG. 6B**

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**FIG. 7A****FIG. 7B**

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AGENT REACTIVE SCHEDULING IN AN AUTOMATED MANUFACTURING ENVIRONMENT

This is a continuation of application Ser. No. 10/135,145 filed Apr. 30, 2002, issued Jun. 14, 2005, as U.S. Pat. No. 6,907,305.

The United States Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Award No. 70NANB7H3041 awarded by the United States Department of Commerce, National Institute of Standards and Technology ("NIST").

BACKGROUND OF THE INVENTION
1. Field of the Invention

This invention pertains to automated manufacturing environments, and, more particularly, to scheduling in an automated manufacturing environment.

2. Description of the Related Art

Growing technological requirements and the worldwide acceptance of sophisticated electronic devices have created an unprecedented demand for large-scale, complex, integrated circuits. Competition in the semiconductor industry requires that products be designed, manufactured, and marketed in the most efficient manner possible. This requires improvements in fabrication technology to keep pace with the rapid improvements in the electronics industry. Meeting these demands spawns many technological advances in materials and processing equipment and significantly increases the number of integrated circuit designs. These improvements also require effective utilization of computing resources and other highly sophisticated equipment to aid, not only design and fabrication, but also the scheduling, control, and automation of the manufacturing process.

Turning first to fabrication, integrated circuits, or microchips, are manufactured from modern semiconductor devices containing numerous structures or features, typically the size of a few micrometers. The fabrication process generally involves processing a number of wafers through a series of fabrication tools. Layers of materials are added to, removed from, and/or treated on a semiconducting substrate during fabrication to create the integrated circuits. The fabrication essentially comprises the following four basic operations:

- layering, or adding thin layers of various materials to a wafer from which a semiconductor is produced;
- patterning, or removing selected portions of added layers;
- doping, or placing specific amounts of dopants in selected portions of the wafer through openings in the added layers; and

- heat treating, or heating and cooling the materials to produce desired effects in the processed wafer.

Although there are only four basic operations, they can be combined in hundreds of different ways, depending upon the particular fabrication process. See, e.g., Peter Van Zant, *Microchip Fabrication A Practical Guide to Semiconductor Processing* (3d Ed. 1997 McGraw-Hill Companies, Inc.) (ISBN 0-07-067250-4). Each fabrication tool performs one or more of four basic operations. The four basic operations are performed in accordance with an overall process to finally produce the finished semiconductor devices.

Controlling a semiconductor factory fabricating such integrated circuits, however, is a challenging task. A semiconductor factory ("fab") is a complex environment where

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numerous parts, typically 40,000 wafers or more, and numerous part types, typically 100 part types or more, are simultaneously being manufactured. As each wafer moves through the semiconductor factory (or, "fab"), it may undergo more than 300 processing steps, many of which use the same machines. A large factory may contain approximately 500 computer-controlled machines to perform this wafer processing. Routing, scheduling, and tracking material through the fab is a difficult and complicated task, even with the assistance of a computerized factory control system.

Efficient management of a facility for manufacturing products such as semiconductor chips requires monitoring various aspects of the manufacturing process. For example, it is typically desirable to track the amount of raw materials on hand, the status of work-in-process and the status and availability of machines and tools at every step in the process. One of the most important decisions is selecting which lot should run on each machine at any given time. Additionally, most machines used in the manufacturing process require scheduling of routine preventative maintenance ("PM") and equipment qualification ("Qual") procedures, as well as other diagnostic and reconditioning procedures that must be performed on a regular basis. These procedures should be performed such that they do not impede the manufacturing process itself.

One approach to this issue implements an automated "Manufacturing Execution System" ("MES"). An automated MES enables a user to view and manipulate, to a limited extent, the status of machines and tools, or "entities," in a manufacturing environment. In addition, an MES permits dispatching and tracking of lots or work-in-process through the manufacturing process to enable resources to be managed in the most efficient manner. Specifically, in response to MES prompts, a user inputs requested information regarding work-in-process and entity status. For example, when a user performs a PM on a particular entity, the operator logs the performance of the PM (an "event") into an MES screen to update the information stored in the MES database with respect to the status of that entity. Alternatively, if an entity is to be put down for repair or maintenance, the operator will log this information into the MES database, which then prevents use of the entity until it is subsequently logged back up.

Although MES systems are sufficient for tracking lots and machines, such systems suffer several deficiencies, the most obvious of which are their passive nature, lack of advance scheduling and inability to support highly automated factory operations. Current MES systems largely depend on manufacturing personnel for monitoring factory state and initiating activities at the correct time. For example, a lot does not begin processing until a wafer fab technician ("WFT") issues the appropriate MES command. And, prior to processing, a WFT must issue an MES command to retrieve the lot from the automated material handling system ("AMHS") with sufficient advance planning that the lot is available at the machine when the machine becomes available. If the WFT does not retrieve the lot soon enough, or neglects to initiate processing at the earliest available time, the machine becomes idle and production is adversely impacted.

These types of deficiencies in the typical automated MES emphasize the importance of the WFT in the efficient operation of the manufacturing process. WFTs perform many vital functions. For instance, WFTs initiate dispatching, transport, and processing as their attention and time permits. They make scheduling decisions such as whether to run an incomplete batch, as opposed to waiting for addi-

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tional approaching lots, or performing PM or qualification procedures instead of processing lots. WFTs perform non-value added MES transactions and utilize conventional factory control systems that are passive. In this context, the term "passive" means activities in the control system must be initiated by the WFT, as opposed to being self-starting or self-initiating.

However, the presence of WFTs also inevitably introduces some inefficiencies. There typically is a large difference between the performance of the best WFT and the performance of the worst WFT. A WFT typically simultaneously monitors the processing of multiple tools and lots, making it difficult to focus on an individual lot or tool. Furthermore, the size and complexity of the modern fabrication process flows makes it exceedingly difficult for a WFT to foresee and prevent downstream bottlenecks or shortages arising from upstream activities. Shift changes, rest breaks, and days off for the WFT also create inefficiencies or machine idle time that adversely impact the manufacturing process flow. Just as the importance of the WFT is magnified by the deficiencies of the automated MES, so are the inefficiencies of the WFT magnified by his importance.

Thus, factory control systems utilized in today's wafer fabs are passive and do not enable a high degree of automation. These systems are very dependent on WFTs and other factory staff to monitor the state of the factory, to continuously react to change, to make rapid logistical decisions, and to initiate and coordinate factory control activity in a timely manner. These WFTs are agents, providing the active element that is lacking in factory control systems. As a result, factory effectiveness in the highly competitive semiconductor industry is quite dependent on the availability, productivity, skill level, and consistency of these human agents. WFTs must monitor and operate a number of tools located in various bays in a fab. They are forced to multiplex across tools, bays, material handling systems and a variety of factory control systems. As a fab's production ramps and more complex processes are introduced, it becomes more difficult to meet the increased complexity and volume without increasing staff or system capabilities. WFTs visibility of upstream and downstream operations, tool state, work-in-process and resource availability is limited.

However, key logistical decisions are frequently based on this limited and dated information, which is only partially provided by factory control systems. WFTs spend a significant amount of time interacting with systems, monitoring factory events and state changes, and performing other non-value added functions, such as MES logging. Shift changes disrupt the operation of the fab as the technicians are temporarily unable to provide required monitoring and coordination. Despite the best efforts of the technicians, utilization of tools suffer, adversely impacting other key factory metrics including cycle time, inventory levels, factory output and mix. With the need for intrabay material handling to transport 12-inch wafers in new 300 mm wafer fabs, significant additional complexity is introduced. Conventional factory control systems are not capable of providing this level of detailed scheduling and execution control.

The present invention is directed to resolving, or at least reducing, one or all of the problems mentioned above.

SUMMARY OF THE INVENTION

The invention, in its various aspects and embodiments, is a method and apparatus for scheduling in an automated manufacturing environment. In one embodiment, a method comprises detecting an occurrence of a predetermined event

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in a process flow; notifying a software scheduling agent of the occurrence; and reactively scheduling an action from the software scheduling agent responsive to the detection of the predetermined event. Alternative embodiments include a computing system programmed to perform this method and a computer-readable program storage medium encoded with instructions to implement this method. In still another embodiment, the invention includes automated manufacturing environment, comprising a process flow and a computing system. The computing system further includes a plurality of software scheduling agents residing thereon, the software scheduling agents being capable of reactively scheduling appointments for activities in the process flow responsive to a plurality of predetermined events.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

FIG. 1 conceptually depicts a portion of one particular embodiment of a process flow constructed and operated in accordance with the present invention;

FIG. 2 conceptually depicts, in a partial block diagram, selected portions of the hardware and software architectures, respectively, of the computing devices in FIG. 1;

FIG. 3 conceptually depicts one particular implementation of the apparatus of FIG. 1, i.e., in a portion of a process flow from a semiconductor fabrication facility, and the manner in which it schedules appointments for the consumption of resources;

FIG. 4 conceptually depicts a calendar of booked appointments;

FIG. 5 conceptually illustrates three related calendars of booked appointments;

FIG. 6A and FIG. 6B conceptually illustrates the changing of booked appointments to take advantage of early start times; and

FIG. 7A and FIG. 7B conceptually illustrate two circumstances in which booked appointments are changed to accommodate unexpectedly long durations for preceding booked appointments.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort, even if complex and time-consuming,

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would be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

FIG. 1 conceptually illustrates a portion of one particular embodiment of a process flow **100** constructed and operated in accordance with the present invention. The process flow **100** fabricates semiconductor devices. However, the invention may be applied to other types of manufacturing processes. Thus, in the process flow **100** discussed above, the lots **130** of wafers **135** may be more generically referred to as "work pieces." The process tools **115** and any process operations performed thereon need not necessarily be related to the manufacture of semiconductor devices in all embodiments. However, for the sake of clarity and to further an understanding of the invention, the terminology pertaining to semiconductor fabrication is retained in disclosing the invention in the context of the illustrated embodiments.

The illustrated portion of the process flow **100** includes two stations **105**, each station **105** including a computing device **110** communicating with a process tool **115**. The stations **105** communicate with one another over communications links **120**. In the illustrated embodiment, the computing devices **110** and the communications links **120** comprise a portion of a larger computing system, e.g., a network **125**. The process tools **115** in FIG. 1 are processing lots **130** of wafers **135** that will eventually become integrated circuit devices. The process flow **100** also includes portions of a MES and an automated materials handling system ("AMHS"), neither of which is shown for the sake of clarity, and other integrated factory controls. The AMHS "handles" the lots **130** and facilitates their transport from one station **105** to another, as well as other locations in the process flow **100**.

As mentioned above, the computing devices **110** may be part of a larger computing system **125** by a connection over the communications links **120**. Exemplary computing systems in such an implementation would include local area networks ("LANs"), wide area networks ("WANs"), system area networks ("SANs"), intranets, or even the Internet. The computing system **125** employs a networked client/server architecture, but alternative embodiments may employ a peer-to-peer architecture. Thus, in some alternative embodiments, the computing devices **110** may communicate directly with one another. The communications links **120** may be wireless, coaxial cable, optical fiber, or twisted wire pair links, for example. The computing system **125**, in embodiments employing one, and the communications links **120** will be implementation specific and may be implemented in any suitable manner known to the art. The computing system **125** may employ any suitable communications protocol known to the art, e.g., Transmission Control Protocol/Internet Protocol ("TCP/IP").

FIG. 2 depicts selected portions of the hardware and software architectures of the computing devices **110**. Some aspects of the hardware and software architecture (e.g., the individual cards, the basic input/output system ("BIOS"), input/output drivers, etc.) are not shown. These aspects are omitted for the sake of clarity, and so as not to obscure the present invention. As will be appreciated by those of ordinary skill in the art having the benefit of this disclosure, however, the software and hardware architectures of the computing devices **110** will include many such routine features.

In the illustrated embodiment, the computing device **110** is a workstation, employing a UNIX-based operating system **200**, but the invention is not so limited. The computing device **110** may be implemented in virtually any type of electronic computing device such as a notebook computer, a

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desktop computer, a mini-computer, a mainframe computer, or a supercomputer. The computing device **110** may even be, in some alternative embodiments, a processor or controller embedded in the process tool **115**. The invention also is not limited to UNIX-based operating systems. Alternative operating systems (e.g., Windows™-, Linux™-, or disk operating system ("DOS")-based) may also be employed. The invention is not limited by the particular implementation of such features in the computing device **110**.

10 The computing device **110** also includes a processor **205** communicating with storage **210** over a bus system **215**. The storage **210** typically includes at least a hard disk (not shown) and random access memory ("RAM") (also not shown). The computing device **110** may also, in some embodiments, include removable storage such as an optical disk **230**, or a floppy electromagnetic disk **235**, or some other form, such as a magnetic tape (not shown) or a zip disk (not shown). The computing device **110** includes a monitor **240**, keyboard **245**, and a mouse **250**, which together, along 15 with their associated user interface software **255** comprise a user interface **260**. The user interface **260** in the illustrated embodiment is a graphical user interface ("GUI"), although this is not necessary to the practice of the invention.

Each computing device **110** includes, in the illustrated embodiment, a software agent **265** residing in the storage **210**. Note that the software agents **265** may reside in the process flow **100** in places other than the computing devices **110**. The situs of the software agent **265** is not material to the practice of the invention. Note also that, since the situs of the 20 software agents **265** is not material, some computing devices **110** may have multiple software agents **265** residing thereon while other computing devices **110** may not have any. Thus, there need not be a one-to-one correspondence between the computing devices **100** and the process tools **115**. Software component(s) **270**, **280** of an automated MES, such as WORKSTREAM™, and of an AMHS, respectively, also reside on at least one computing device **110**. As with the 25 software agent(s) **265**, the software components **270**, **280** may reside anywhere within the process flow **100**.

Referring now to FIG. 1 and FIG. 2, the software agents **265** each represent some "manufacturing domain entity," e.g., a lot **130**, a process tool **115**, a resource, a PM, or a Qual. A process tool **115** may be a fabrication tool used to fabricate some portion of the wafers **135**, i.e., layer, pattern, dope, or heat treat the wafers **135**. Or, the process tool **115** may be a metrology tool used to evaluate the performance of various parts of the process flow **100**. The software agents **265**, collectively, are responsible for efficiently scheduling and controlling the lots **130** of wafers **135** through the fabrication process. In furtherance of these objectives, the software agents **265** interface with the software components **270**, **280** of the MES and AMHS, respectively, and are integrated with other existing factory control systems (not shown). The software agents **265**, where appropriate, also 30 interface with the process tools **115** and other equipment through a software implemented "equipment interface" ("EI") (not shown). As will be apparent to those skilled in the art having the benefit of this disclosure, the manner in which this interface and integration occurs is implementation specific, depending upon the makeup and configuration of the MES, the AMHS, and the other factory control systems.

Of particular interest to the present invention, the software agents **265** reactively schedule, initiate, and execute activities on behalf of their respective manufacturing domain entities. In the illustrated embodiment, the software agents **265** also proactively schedule activities. Collectively, the 35

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software agents 265, among other things, schedule ahead for each lot 130 one or more operations on a specific qualified process tool 115, including transports and required resources, as discussed further below. This includes making optimizing decisions such as running an incomplete batch, as opposed to waiting for an approaching lot 130, and scheduling opportunistic preventive maintenance (“PM”) procedures or qualification tests (“Quals”) to meet specifications. The software agents 265 schedule and initiate activities such as lot transport and processing; perform MES transactions; monitor processing and transport; and react to unscheduled activities or deviations from scheduled activities. Furthermore, in the illustrated embodiment, the software agents 265 are configurable in a manner that allows a user to influence their behavior in order to tune the performance of the process flow 100.

In the illustrated embodiment, the scheduling agents 265 are typed by the manufacturing domain entities they represent. There may be many different types of scheduling agents 265, depending on the implementations. The principle types of scheduling agents 265 in the illustrated embodiment, shown in FIG. 3, include:

- a Lot Scheduling Agent (“LSA”) 305 that schedules activities on behalf of lots 130 of wafers 135;
- a Machine Scheduling Agent (“MSA”) 310 that schedules activities on behalf of process tools 115;
- a PM Scheduling Agent (“PMSA”) 315 that schedules activities on behalf of PMs and Quals (not shown); and
- a Resource Scheduling Agent (“RSA”) 320 that schedules activities on behalf of resources (not shown).

However, other types may be employed in addition to, or in lieu of, those shown. The roles and functions of each of these of scheduling agents 265 in the illustrated embodiment will be more fully discussed below.

Some of these activities are scheduled reactively, i.e., in response to events occurring in, e.g., the process flow 100, in accordance with the present invention. In one particular embodiment, this includes:

- detecting an occurrence of a predetermined event in a process flow, e.g., the process flow 100;
- notifying a subscribing software scheduling agent, e.g., the LSA 305, the MSA 310, the PMSA 315, or the RSA 320, of the occurrence; and
- reactively scheduling an action responsive to the detection of the predetermined event.

The predetermined event and the reactively scheduled action will be implementation specific. Several exemplary events and reactively scheduled actions are discussed further below.

Note that this type of reactive scheduling implies a knowledge that such events are occurring within the process flow 100. To this end, the software agents 265 respond to additional software components, not shown, known as “publishers” (or, “notifiers”) and “subscribers.” Agents create listeners which subscribe to one or more notifiers. Notifiers “publish” events to their subscribing listeners when changes occur within the factory. Listeners, in turn, call their subscribing software agent 265. For example, when a MSA is created, the agent will create a machine listener that subscribes to specific machine events. The MSA is interested in receiving any changes that occur to a particular machine. For example, if the availability of the machine changes, the publisher will publish the event to all of its listeners. The machine listener will then notify the subscribing MSA about the event. The subscribing MSA will then react appropriately.

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More particularly, when the software agents 265 are created, they create listeners and subscribe to published events by adding the listeners to the event publisher. Listeners enable the software agents 265 to react to events in the process flow 100 in an appropriate manner. Table 1, below, lists the relevant software agents 265 employed in the illustrated embodiment, the listeners they create, and a description of their function. Note that the use of publishers and subscribers via listeners and notifiers in this manner is known to the art, and any suitable technique may be employed.

TABLE 1

Software Agents and Associated Listeners		
Software Agent	Associated Listeners	Reason for Subscribing
LSA	Equipment Event Listener	Listens to events from the Equipment Interface. Events may include loading started, charging started, loading completed, charging completed, etc.
	Machine Listener	Listens to MES events that occur on the machine. For example, it listens when a machine is not available and reacts appropriately.
	Process Operation Listener	Listens to changes within a process operation since it might change the processing capability of a machine.
	Process Listener	Listens to changes within a process since it might change the processing capability of a machine.
	Alarm Listener	Listens to alarms that have been set at start or end times for scheduled activities.
	Schedule Advertisement Listener	Listens to “advertised” time slots for scheduled appointments that have not started.
	Appointment State Change Listener	Listens to any corresponding appointments on scheduling calendars of other agents that might affect its calendar.
	Alarm Listener	Listens to alarms that have been set at start or end times for scheduled activities.
	Lot Listener	Listens to MES events that occur on the lot, such as product change, priority change, wafer count, and so on.
	AMHS Listener	Listens to changes in the location of the lot of represented by the LSA.
MSA	Appointment State Change Listener	Listens to any corresponding appointments on scheduling calendars of other agents that might affect its calendar.
	Alarm Listener	Listens to alarms that have been set at start or end times for scheduled activities.
	Process Operation Listener	Listens to changes within a process operation since it might change the processing capability of a machine.
	Machine Listener	Listens to MES events occurring on the machine. For example, it listens when a machine is not available.
	Appointment State Change Listener	Listens to any corresponding appointments on scheduling calendars of other agents that might affect its calendar.
	Chamber Listener	Listens to MES events that occur at chamber level, such as downtime, PM, or Quals.
	Process Listener	Listens to changes within a process since it might change the processing capability of a machine.

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TABLE 1-continued

Software Agents and Associated Listeners		
Software Agent	Associated Listeners	Reason for Subscribing
PM Scheduling Agent ("PMSA")	Equipment Event Listener	Listens to events from the Equipment Interface. Events may include carrier arriving at the machine port, processing started, processing near complete, carrier departed, etc.
	Chamber Listener	Listens to MES events that occur at chamber level, such as downtime, PM, or Quals.
	Machine Listener	Listens to MES events that occur on the machine. For example, it listens when a machine is not available.
	Qual Collection Listener	Listens to any new Quals or deleted Quals.
PM Collection Listener		Listens for any new PMs or deleted PMs.
Appointment State Change Listener		Tracks changes to any appointments that might affect his calendar.

As is evident from Table 1, the software agents 265 listed therein listen to appointment changes that might affect their calendar. Consider, for example, FIG. 5 (discussed in more detail below) in conjunction with Table 1. FIG. 5 illustrates different appointments (SETUP₁, LOT₁, MOVE₁, TOOL₁, PM, QUAL, etc.) that are contained within the calendars for each of several agents (the MSA for TOOL₁, the LSA for LOT₁, a PMSA, and a RSA). FIG. 5 also illustrates corresponding appointments between those calendars. For example, the MSA calendar contains a processing appointment LOT₁ that corresponds with the processing appointment TOOL₁ on the LSA calendar. These two appointments are actually for the same event (i.e., the processing of LOT₁ on TOOL₁) made by two different entities (i.e., the MSA and the LSA, respectively) for two different entities (i.e., the lot LOT₁ and the processing tool TOOL₁).

Referring now to both FIG. 3 and FIG. 5, when corresponding appointments (e.g., LOT₁, TOOL₁) are created, the appointments themselves may contain a collection of listeners, e.g., the listeners 356, 358 in FIG. 3. Listeners are added to the appointment when other software agents 265 want to be notified that the appointment has changed. In this case, the lot processing appointment LOT₁ on the MSA calendar 370 contains a listener 356 that notifies the LSA 305 through a notifier 354 when the processing appointment LOT₁ changes. On the other hand, the lot appointment TOOL₁ contains a listener 358 that notifies the MSA 310 through a notifier 352 when it changes. If the MSA 310 changes the processing appointment LOT₁, the LSA 305 will be notified of the appointment change and it will modify the appointment TOOL₁ accordingly. Thus, listeners enable the software agents 265 to synchronize the corresponding appointments. Also, the software agents 265 can schedule reactively to such predetermined events when appropriate and can then keep their calendars updated as changes are instituted by other software agents 265.

When the software agents 265 react to appointment changes, they carefully manipulate the corresponding appointments. In some cases, it would be inappropriate for two software agents 265 to manipulate their respective corresponding appointments at the same time. Thus, a single software agent 265 is responsible for manipulating its respective corresponding appointment, which will then prompt the software agent 265 of the corresponding appoint-

ment to manipulate its respective corresponding appointment. For example, in FIG. 5, the LSA 305 contains a move appointment MOVE₁ followed by the lot processing appointment TOOL₁. If the end time for the move appointment MOVE₁ arrives but the appointment is not finished, an alarm listener notifies the LSA 305. ("Alarms" are one type of event listened for, and are discussed further below.) The LSA 305 then expands the duration of the move appointment MOVE₁ by a configurable amount of time, but also shifts the lot processing appointment TOOL₁ to accommodate the expansion of the move appointment MOVE₁.

At the same time, the alarm listener for the MSA 310 will notify it that the start of the lot processing appointment TOOL₁ has arrived. Since the LSA 305 can best determine when the lot LOT₁ should arrive at the process tool 115, the LSA 305 shifts the start time of the lot processing appointment TOOL₁ after expanding the move appointment. The MSA 310 will wait for its appointment state change listener to notify it of the shift to the lot processing appointment, will find its counterpart lot processing appointment, and shift it accordingly. In this circumstance, the MSA 310 will ignore its own start time alarm. Although not shown, the lot 130, process tool 115, resources, and PMs and Quals all have corresponding "processing" agents, also not shown, that are notified by the scheduling agents when significant events occur that may require processing.

In furtherance of their proactive and reactive scheduling duties, the software agents 265 maintain calendars, such as the calendar conceptually illustrated in FIG. 4, of scheduled "appointments." FIG. 4 conceptually illustrates a calendar containing information concerning appointments for, e.g., a process tool 115 for a number of lots 130. An "appointment" is a time period certain in which the process tool 115 has obligated itself to perform the process operation, and is defined by an Appointment Start Time ("TS") and an Appointment End Time ("TE"). In the illustrated embodiment, the appointments are booked within "commitment windows" ("CW"), or time windows defined by an Earliest Start Time for processing ("EST") and a Latest Delivery Time ("LDT_p"). The client lot 130 commits to arrive at the process tool 115 no later than the EST and the process tool 115 commits to complete the processing no later than the LDT. Note, however, that the use of commitment windows are not necessary to the practice of the invention.

In FIG. 4, the process tool 115 has booked appointments APP₁-APP₄ for lots Lot₁-Lot₄, respectively. Thus, the calendaring information for Lot₁-Lot₄ is as follows:

Lot₁: APP₁[t₁₀, t₁₂], CW₁[t₈, t₁₄]
 Lot₂: APP₂[t₁₃, t₁₅], CW₂[t₉, t₁₆]
 Lot₃: APP₃[t₅, t₇], CW₃[t₂, t₁₁]
 Lot₄: APP₄[t₃, t₄], CW₄[t₁, t₆]

Note that, in the illustrated embodiment, several of the commitment windows overlap, but none of the appointments overlap. Appointments may be shifted within their commitment window, so long as they do not overlap other appointments, or may be expanded, shrunk, canceled and rescheduled as is discussed more fully below. However, in some embodiments, parts of the appointments may overlap.

Thus, returning to FIG. 3, appointments, e.g., the processing appointment 375, are proactively booked on calendars, e.g., the calendars 385, 370, maintained by each scheduling agent, e.g., the scheduling agents 305, 310. Note, however, that not all appointments are processing appointments. Whenever the processing appointment 375 is booked, the LSA 305 schedules move appointments for moving the lots 130 to the location of the newly booked processing appointment 375. For instance, referring to FIG. 1 again,

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assume the lots **130** processing on the first process tool **115** exits from a port **140** and needs to arrive at the port **145** of the second process tool **115** for the scheduled processing appointment **375**. Each LSA **305** schedules the appointments for the lot **130** to transit between the source and destination locations, e.g., the port **140** of the first process tool **115** and the port **145** of the second process tool **115**.

FIG. 5 conceptually illustrates three related calendars maintained for three different types of entities—a lot **130**, a process tool **115**, and a preventive maintenance (“PM”—on which different types of appointments are booked. In the illustration of FIG. 5, as opposed to the illustration of FIG. 4, all appointments for a given calendar are collapsed onto a single timeline. The commitment windows for each appointment are omitted to facilitate this collapse and to keep from unduly cluttering the illustration. More particularly, FIG. 5 illustrates:

- a calendar for a process tool $TOOL_1$ maintained by a MSA for the process tool $TOOL_1$, including appointments booked for setups (e.g., $SETUP_1$, $SETUP_2$);
- lot processing appointments (e.g., LOT_1 , LOT_2 , LOT_3);
- PMs (e.g., PM); and
- Quals (e.g., QUAL);

- a calendar for a lot LOT_1 maintained by a LSA for the lot LOT_1 on which are booked appointments for moves (e.g., $MOVE_1$, $MOVE_2$, $MOVE_3$, $MOVE_4$, $MOVE_5$) and lot processing appointments (e.g., $TOOL_1$, $TOOL_2$); and

- a calendar for a PM maintained by a PMSA on which are booked appointments for PMs (e.g., PM), and Quals (e.g., QUAL).

Still other types of appointments may be booked. For instance, if the process tool $TOOL_1$ goes down, i.e., is no longer available for processing, a “downtime appointment” may be booked on its calendar to represent the expected repair time. Note that each of these appointments in the calendar of FIG. 5 is for an event that, in the first instance, the software agents **265** proactively schedule according to the manufacturing domain entity they represent.

An appointment, e.g., the processing appointment **375** in FIG. 3, exists in one of several “states”, or have a certain “status,” at any given time. In the illustrated embodiment, the status may be:

- tentative—the appointment has been created, but not booked (which is discussed further below);
- unready—the tentative appointment has been booked, but is not ready for execution;
- ready—the lot **130** involved in the appointment has arrived at the process tool **115** for which it is booked;
- active—the start time for the appointment has arrived and all participants are ready;
- active PM/Qual—the start time for a following Qual portion of a PM appointment has arrived;
- processing—the scheduled activity has started, i.e., the start command has been confirmed by the process tool **115**, or the PM or Qual has started;
- processing PM/Qual—the follow-up Qual portion of a PM has started;
- near complete—the appointment is nearing completion as defined by predetermined parameters (e.g., processing time remaining, wafer count);
- complete—processing is completed;
- canceled—booked appointment is removed from a calendar before it enters the processing status; and
- aborted—appointment was stopped during processing in a processing status.

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A tentative appointment remains tentative until it is booked, whereupon it enters the unready status. The appointment is unready until the lot **130** arrives at the process tool **115**. The appointment is then ready until the start time for the appointment arrives. The appointment then becomes active (i.e., the appointment commences) until the process tool **115** confirms it has started processing. Once the appointment is processing, it retains that status until it nears completion and then is complete. If the appointment is removed from the calendar before entering the processing state, it is “canceled” and removed from the system. Once in the processing status, the appointment is “aborted” if halted. A completed appointment or an aborted appointment retains this status until it is removed from the system.

However, in accordance with the present invention, the software agents **265** also reactively schedule events for their respective manufacturing domain entities resulting from developments in the process flow **100**. Typically, reactive scheduling by the software agents **265** effects changes to appointments that were, in the first instance, proactively scheduled. However, this is not necessary to the practice of the invention. For instance, in one particular embodiment, the software agents **265** schedule activities in reaction to a machine failure which causes the machine to stop processing and requires a period of downtime in order to repair the machine. There usually would not be any proactively scheduled appointment for such an event since a machine failure usually cannot be predicted in advance.

More particularly, the software agents **265** usually react to different events that occur within the process flow **100**. These events are identified beforehand, i.e., are “predetermined,” so that appropriate activities in reaction to those events can be defined. The appropriate actions will depend on a number of factors including not only the type of manufacturing domain involved, but also the type of event that is involved. The predetermined events are categorized, in the illustrated embodiment, as one of three types: appointment state change, a factory state change, or an alarm event.

Appointment state changes usually occur when a software agent **265**, e.g., the scheduling agents **305**, **310** change an appointment, e.g., the processing appointment **375**. A software agent **265** may change the status of the appointment, expand or shrink the appointment, cancel the appointment, shift the appointment, or perform other manipulations to the calendar or appointments on the calendar. When an appointment is changed, the appropriate agents **265** react to the change. For example, the MSA **310** may expand the scheduled duration of the appointment **375** on its calendar **370** due to the appointment **375** running late. The LSA **305** reacts to that change by expanding the corresponding appointment **375** on its calendar **385** to keep the appointments **375** synchronized across the two calendars **370**, **385**. Appointment state changes may include, for instance, appointment cancellations, appointment expansions, appointment shrinkage, appointment aborts, appointments changing status, appointments shifting, and commitment window updates.

Factory state changes usually occur when the state of the factory, e.g., the process flow **100**, changes. Factory state change events may originate from the MES **270** (shown in FIG. 2), the AMHS **280** (also shown in FIG. 2), or from the Equipment Interface (“EI”, not shown) for the process tools **115**. Factory state changes may include lot due date changes, a lot being put on hold, changing the process or process operation of a lot, a lot’s location changing, a carrier arriving at a machine port, etc. For every factory state change that is a “predetermined event,” the software agents **265** react accordingly. Exemplary factory state changes might include

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a downtime occurrence; a machine becoming available; a PM/Qual being detected; a chamber going down; a lot departing a machine; a move completed; and a wafer completed.

Alarm events occur, in this particular embodiment, when a specific alarm has expired. Agents react when an alarm event is received—for example, when the appointment end time has arrived for a lot appointment. If the machine agent does not receive notification that the appointment has ended, the machine agent will expand the appointment based on a configurable percentage of the appointment's total duration. Once the appointment is expanded, the machine agent will set a new alarm for the new, predicted end time of the appointment. An alarm event might be, for instance, an alarm firing for an appointment start time or an alarm firing for an appointment end time.

Note that some events are unplanned, or unexpected. For instance, there is no reliable way to actually know when a machine or chamber goes down unless it is going down for a scheduled PM or a Qual period. Some of these events are expected. For instance, the time at which a lot **130** arrives at the port **145** of the process tool **115** should be known if it arrives on time since the move was scheduled. Some embodiments may therefore choose not to schedule reactively to such an event, instead preferring to schedule proactively on the assumption the schedule will be met and scheduling reactively only if the schedule is not met. Note that other embodiments may schedule reactively to events not listed either in addition to or in lieu of those set forth herein.

The reactive scheduling performed upon the occurrence of any particular event will depend on the nature of the event and, to some degree, upon the particular implementation. Generally speaking, the reactive scheduling typically includes changing appointments, e.g., the appointment **375** in FIG. 3, previously scheduled and booked. Booked processing appointments and PM/Qual appointments may be shifted, expanded, aborted, shrunk, canceled, and re-scheduled. Move and setup appointments are modified as needed at the time lot processing appointments are modified. In the illustrated embodiment, these appointment modifications are performed by the LSA **305** or the MSA **310**.

For example, booked processing appointments may be shifted, which may cause booked move appointments to be canceled, aborted, or rescheduled. Appointments are viewed as “beads on a string”. Existing appointments are permitted to slide backward or forward in time (i.e., “right” or “left” in FIG. 4 and FIG. 5) within their respective commitment windows as desired to accommodate changes in scheduling. In the illustrated embodiment, to simplify the logic, appointments are not permitted to shift past the next appointment in either direction.

Consider the circumstance where a lot processing appointment for a lot **130** completes earlier than expected. This provides an opportunity for the MSA **310** to reactively schedule what is known as an “early start.” Because the MSA **310** in FIG. 3 is idle, the MSA **310** will attempt to shift the next appointment to an earlier start time and start it immediately. When the lot **130** completes the processing appointment early, the MSA **310** reacts by shifting subsequent scheduled appointments earlier in time to take advantage of the early start opportunity. The LSA **305** will react differently to the event of the lot processing completing early.

This instance is shown in FIG. 6A, wherein the current time t_c falls within the commitment window CW_1 for the next appointment APP₁. The next appointment APP₁ is then

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shifted left, or earlier in time, so that its processing can begin immediately. If the next booked appointment cannot be shifted to start at the current time, the MSA **310** will search for any other booked appointments that may have commitment windows starting at the current time or earlier. If one of these booked appointments can be moved to start immediately without causing cancellation of any other booked appointments, the booked appointment will be moved in a “jump over” fashion and other booked appointments will be shifted as required. This scenario is shown in FIG. 6B, wherein the current time t_c at which the provider is idle is outside the commitment window CW_1 for the next booked appointment APP₁, but falls within the commitment window CW_3 of the third booked appointment APP₃. Hence, the third appointment APP₃ performs a “jump over” operation, jumping over appointments APP₁ and APP₂ and appointment APP₁ is shifted right to a later start time immediately following appointment APP₃.

In either situation, the LSAs **305** for the affected lots **130** are notified by that their appointments have been changed. The difference in start times and end times may also change the appropriateness of scheduled moves. For instance, if a booked appointment is shifted left, the earlier start time means the lot **130** must arrive earlier than may be provided for by the currently scheduled moves. Conversely, a later start time means the lot **130** should move later. In either circumstance, modified moves may be appropriate to achieve the correct arrival time for the lot **130**.

Consider also the circumstance where the software agents **265** reactively schedule because the duration of a current appointment, or an appointment immediately preceding it, is longer than expected. When the LSA **305** and MSA **310** book appointments, they set an “end-time alarm” (not shown) that notifies them when the appointment is scheduled to be completed. When the task is completed, the scheduling agents **305**, **310** are notified and these alarms are canceled. Thus, if the alarm fires, then the scheduling agents **305**, **310** know the appointment did not complete at the scheduled time, and that the appointment needs to be expanded.

FIG. 7A and FIG. 7B illustrate two such situations. The timelines for the appointments in each have been collapsed and the commitment windows are omitted as was the case for the calendars in FIG. 5. In FIG. 7A, the move MOVE₃ had a longer duration than was expected, and so the moves MOVE₄, MOVE₅ and the appointment APP₂ were shifted later in time to accommodate this longer duration. In FIG. 7B, the appointment APP₃ took longer than was expected, and so the appointments APP₄ and APP₅ were shifted later in time. Note that in both FIG. 7A and FIG. 7B, the illustrated changes necessarily imply that, in both circumstances, the commitment windows for the changed appointments were wide enough to accommodate the changes. Otherwise, some appointments would have to be canceled.

As can be seen from these two examples, the reactive scheduling will vary according to the circumstance. In general, in the illustrated embodiment, the following scheduling activities may occur responsive to a predetermined event:

- 60 aborting a scheduled appointment in progress;
- canceling a scheduled appointment before it begins;
- scheduling a new appointment;
- starting a scheduled appointment;
- expanding the duration of a scheduled appointment;
- shrinking the duration of a scheduled appointment;
- shifting a scheduled appointment to an earlier or later time;

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changing a commitment window;
 changing an appointment attribute (e.g., transport start time, remaining transport time, etc.);
 setting an alarm;
 canceling an alarm; and
 changing the status of an appointment.

The “predetermined events” provoking such reactive scheduling may include, for an appointment state change:
 canceling an appointment;
 expanding an appointment;
 shrinking an appointment;
 aborting an appointment;
 an appointment changing status;
 shifting an appointment;
 an unexpected carrier arrival;
 a transport time update;
 a load time update;
 an unload time update;
 a lot joining a batch;
 a lot leaving a batch;
 canceling a lot from a batch; and
 updating a commitment window.

For a factory state change, the predetermined event might be, for example:

detection of downtime;
 a machine becoming available;
 a PM/Qual being detected;
 a chamber going down or coming up;
 a change in machine capabilities;
 a change in machine types;
 addition of a process;
 addition of a process operation;
 a lot process changed;
 a lot placed on hold;
 a lot released from hold;
 a lot priority changed;
 a lot due date changed;
 a lot wafer count changed;
 a lot process operation changed, and
 a lot departing from or arriving at a machine.

And, for an alarm event, the predetermined event might be:

an alarm firing for an appointment start time; and
 an alarm firing for an appointment end time.

Note that these lists are not exhaustive, but illustrative only. The identity of predetermined events will be implementation-specific, and so may vary among embodiments. Typically, depending on the event provoking the reactive scheduling, these activities will be employed in combination, or in the alternative, conditionally. Tables 2–5 list the predetermined events, their type, and their reactive scheduling activities for machine, lot, PM, and resource scheduling agents, respectively, for one particular implementation of the present invention.

Tables 2, Table 3, and Table 5 refer one or more of load/unload operations and appointments and charge/discharge operations and appointments. As will be appreciated by those skilled in the art having the benefit of this disclosure, some process tools 115 perform lot batch process operations in which multiple lots 130 are simultaneously processed in a batch. Some of these process tools 115 use load, charge, discharge and unload steps. For instance, a process tool 115 may first load all the batch participants, i.e., lots 130, from the tool I/O ports (not shown) to the tool internal stocker (also not shown). Usually this type of process tool 115 has multiple I/O ports, and the load/unload

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operations are also performed in batches. After all the batch participants are loaded, the process tool 115 performs a batch charge operation to move the batch participants from the internal stocker into, e.g., a furnace tube (not shown) before the processing can actually begin. After the process tool 115 completes the batch process operation, it discharges the batch participants, e.g., from the furnace tube back into the internal stocker. Finally when the lots 130 are ready to be moved to the tool I/O ports, a sequence of batch unload operations is performed.

Table 2 also refers to appointments that are “locked.” To help prevent undesirable appointment shifting, the illustrated embodiment employs an appointment locking mechanism. Generally speaking, when a lot 130 starts its final move from a source location to a process tool 115, it is undesirable to have a new appointment jumping in front of it by canceling or shifting that appointment to the right, or later in time. To prevent this from occurring, the MSA “locks” the lot processing appointment when the lot 130 starts its final move. Note that locked appointments nevertheless sometimes do need to be shifted. For instance, assume two appointments are booked on the calendar for a particular process tool 115, and the first one is processing while the lot 130 for the second one has started the final move to the process tool 115. The second appointment is locked because it is in its “final” move to the process tool 115. If the first appointment runs long and must be expanded, the second one must first be shifted to permit the first one to expand. Thus, the locked second appointment must be shifted even though this is generally undesirable. In general, however, appointments may be “locked” in certain circumstances to prevent them from being shifted or canceled.

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TABLE 2

Reactive Scheduling Activities for MSAs			
	Event	Event Type	Reactive Scheduling Activities
40	Downtime Detected	Factory State Change (MES)	A downtime event may indicate the machine is currently not available for processing or that an error has occurred during processing. If the MSA detects that the machine is not currently available for processing, the MSA will abort and shrink any lot processing appointment that is processing. It will then book a downtime appointment after the aborted lot processing appointment or after the unload appointment. If the downtime event occurred due to an error during processing, the MSA will book a downtime appointment after the lot processing appointment that is processing or the unload appointment. Booked processing appointments overlapping the downtime appointment are shifted later in time, if possible, or are otherwise cancelled.
45	Machine Available Detected	Factory State Change (MES)	Any active PM, QUAL, or downtime appointments are completed. The next appointment on the machine's calendar is then shifted and started, if possible.
50	PM/Qual Detected	Factory State Change (MES)	A PM/Qual appointment is booked after any active appointments. Any booked appointments overlapping the PM/Qual appointment are shifted after the PM/Qual appointment. If any overlapping booked appointment cannot shift, it is cancelled.
55	Chamber Down Detected	Factory State Change (MES)	All unready appointments for the machine or chamber that has not started are canceled.
60	Chamber Up Detected	Factory State Change (MES)	The duration for any appointment is shrunken to the expected completion time
65			

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TABLE 2-continued

<u>Reactive Scheduling Activities for MSAs</u>		
Event	Event Type	Reactive Scheduling Activities
	(MES)	based on the new throughput rate and shifted to the right, or later in time, if possible.
Lot Not At a Port At a Scheduled Start Time	Alarm State Change	If the lot has “reserved” a port with the machine, the MSA will wait until the LSA expands the move appointment. The expansion of the move appointment will cause the LSA to shift the lot appointment to the right. The MSA will then react appropriately to the shifting of the lot appointment. If the lot has not reserved the port, the appointment is cancelled.
Lot Arrived at Machine Port	Factory State Change (EI)	If the lot arrived at the right location, the MSA will make the appointment active if it is not a participant of a batch appointment. If the appointment is a participant of a batch appointment, the MSA will make the appointment ready. If the machine is idle and the appointment is active, the MSA will start processing the appointment. (Note: a participant of a batch appointment is made active when all of the participants have arrived at the machine.) If the lot arrived at the right machine but the wrong port, the MSA will check to see if a different lot reserved the port. If a different lot reserved the port, the MSA will assign that lot the next available port. If the appointment for the arriving lot is active, the MSA will start processing the appointment. If the lot arrived at the wrong machine, the MSA will check to see if a different lot reserved the port. If a different lot reserved the port, the MSA will assign that lot the next available port. The machine will then book an appointment for the lot just arrived. Any overlapping appointments will be shifted to a later time. If an overlapping appointment cannot shift later in time, it will be cancelled.
Lot Processing Appointment Running Late	Alarm State Change	If a lot processing appointment is running late, it is expanded and any overlapping booked appointments are shifted to the right, or later in time. If any overlapping booked appointment cannot shift right and the appointment is not locked, it is cancelled. If the appointment is locked and cannot shift right, the appointment’s commitment window will be expanded to allow the shift to occur.
Lot Processing Completing Early	Factory State Change (EI)	If a lot processing appointment completes earlier than expected, the appointment is shrunk and completed and, if possible, the next appointment is shifted earlier in time. If the next appointment can shift to the current time, it will start that appointment.
Lot Processing Near Complete Detected	Factory State Change (EI)	The MSA calculates the remaining processing time for the lot. If it is going to finish early, the appointment is shrunk to the new end time and any following appointments are shifted left, or earlier in time. If it is going to finish late, the appointment is expanded to the new end time and any overlapping appointment are shifted to a later time or cancelled.
Lot Appointment State Change Cancelled	Appointment State Change	If processing or near complete, the appointment is aborted or, if unready, simply canceled. Upon cancellation of an appointment, the next appointment is shifted earlier in time, if possible, to reduce any gaps between appointments.
Lot Departing Machine Port	Factory State Change (EI)	If the lot was still processing at the time of its departure, the appointment is aborted and the end time shifted earlier in time. The next appointment is shifted earlier as much as possible.

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TABLE 2-continued

<u>Reactive Scheduling Activities for MSAs</u>		
Event	Event Type	Reactive Scheduling Activities
Shift Appointment Right	Appointment State Change	The appointment is shifted right. If it cannot be shifted right, it is canceled, unless it is locked. If it is locked, any appointment blocking the right shift are cancelled
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Table 3 refers to “feeder operations.” In a partially automated fab, only a portion of the process operations may be scheduled and controlled by the software agents 265. Thus, 15 only a subset of the process tools 115 in the fab are under the control of the software agents 265 and the fab is not fully under the control of this system. Those process operations controlled by the software agents 265 are called “control process operations.” Immediately before each control process operation, a sequence of “feeder” operations can be derived from a configurable percentage of the process time of the controlled process operation. Feeder appointments are used in determining the earliest start time for an appointment being scheduled ahead. More particularly, feeder appointments 20 are used when a LSA is scheduling ahead and the time has not yet arrived for scheduling the feeder operation with an actual process tool 115. Feeder appointments are used to represent processing activities for those feeder operations with the duration equal to the cycle time of the respective 25 feeder operations.

Table 3 also refers to “maxMove” appointments. For a feeder operation, the specific process tool 115 that will perform the final feeder operation is not known until the lot 30 begins processing at the final feeder operation. A 35 “maximum move” appointment represents transport activities from the last feeder process tool 115 to a controlled process tool 115. In one embodiment, the duration of the maximum move appointment is derived by the worst case transport time between the last feeder process tool station 40 105 and the controlled process tool station 105. When the last feeder appointment is activated, the actual process tool 115 performing the last feeder operation is known, and thus the maximum move appointment will be replaced by a move 45 appointment or a sequence of move appointments.

Table 3 furthermore refers to a “bid request.” In the illustrated embodiment, the process flow 100 employs a protocol for scheduling appointments that begins with a “bid request.” The LSA 305 publishes a “request bid” message to a capable MSA 310. The MSA 310 submits one or more bids 50 to the LSA 305. The LSA 305 selects one from among several such bids, which typically results in one or more “appointments” associated with performing the operation the LSA 305 is seeking for its lot 130 of wafers 135. Note, 55 however, that other protocols may be employed in which there is no “bid request.” Thus, the bid request is an implementation specific feature that may not be found in all embodiments.

TABLE 3

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
60		
Appointment End Time Alarm Fired For Move	Alarm Event	The alarm indicates that the scheduled end time of the move appointment has arrived. The LSA determines if the

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TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
Appointment		move appointment should be expanded. If the move originates from a machine port, move appointment expansion is always permitted to clear the port. Otherwise, the move appointment is expanded a percentage (i.e., 25%) of the originally scheduled duration until a maximum expansion percentage has been reached (i.e., 175%). When the maximum expansion percentage has been reached, the appointment is aborted. If the move appointment is expanded, subsequent booked appointments are shifted later in time. A new end time alarm is then set for the expanded move appointment.
Appointment End Time Alarm Fired For Feeder Appointment	Alarm Event	The alarm indicates that the scheduled end time of the feeder appointment has arrived. The LSA will expand the appointment by a configurable percentage. Any subsequent feeder appointments (if any) will be shrunk by the amount that this feeder appointment expanded (can't shrink a feeder duration to be less than the process time for the operation). As a last resort, appointments after the final feeder appointment will be shifted to a later time.
Appointment Start Time Arrived For Move Appointment	Alarm Event	This alarm indicates that the scheduled start time of the specified move appointment has occurred. The LSA will make the appointment active if it is not active and the AMHS move will be initiated. If the appointment is the final move before a lot appointment, the LSA will ask a MSA to reserve a port and lock the appointment. It will also appropriately update the total transport time and remaining transport time. The LSA will then create an appointment end time alarm.
Appointment Start Time Arrived For Feeder Appointment:	Alarm Event	This alarm indicates that the scheduled start time of the specified feeder appointment has occurred. The LSA will make the appointment active if it is not active. The LSA will then create an appointment end time alarm.
Lot Appointment Completed	Appointment	The LSA cancels the lot appointment and any non-also cancel the end time alarm, appropriately updates the transport start time, and initiates the next appointment.
Make Lot Appointment Near Complete	Appointment State Change	The MSA initiates this change when it receives an equipment event stating that the lot processing is near complete. The LSA will change the status of the appointment to near complete. It will then schedule the post control move appointment and invokes scheduling for the next process operation if appropriate.
Shift Lot Appointment Left	Appointment State Change	The LSA will try to move the lot appointment to the left, or earlier in time. If it is unable to shift left, the system will cancel all non-active move, load, and unload appointments and then cancels the lot appointment.
Shift Load Appointment Left	Appointment State Change	The LSA will try to move the load appointment to the left. If it is unable to shift left, the system will cancel all non-active move appointments, cancels unload/load appointments, cancels the lot appointment.

TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
5 Shift Unload Appointment Left	Appointment State Change	The LSA will try to move the unload appointment to the left. If it is unable to shift left, the system will cancel all non-active move appointments, cancels unload/load appointments, and cancels the lot appointment.
10 Shift Lot Appointment Right	Appointment State Change	The LSA will check to see if the first appointment is a move appointment. If it is a move appointment and it is not active or on a machine or machine port, it will shift that move appointment to make it arrive at the start of the lot appointment or load appointment (if the move appointment is active, it will expand the end to the start of the lot appointment or load appointment). It will then shift any preceding appointments to the right. If the system is unable to shift the appointments right, it will cancel all non-active move appointments, any load/unload appointment, and the lot appointment.
15		
20		
25 Shift Load Appointment Right	Appointment State Change	The LSA will check to see if the previous appointment is a move appointment. If it is a move appointment and it is not active or on a machine or machine port, it will shift that move appointment to make it arrive at the start of the load appointment (if the move appointment is active, it will expand the end to the start of the load appointment). It will then shift any preceding appointments to the right. If the system is unable to shift the appointments right, it will cancel all non-active move appointments, any load/unload appointments, and the lot appointment.
30		
35 Shift Unload Appointment Right	Appointment State Change	The LSA will shift appointments to the right. If the system is unable to shift the appointments right, it will cancel the lot appointment, which will cancel all move, load, and unload appointments association with the lot appointment.
40		
45 Shrink Lot Appointment	Appointment State Change	The LSA will shrink the lot appointment to the specified time and shift subsequent move appointments earlier in time.
50 Shrink Load Appointment Shrink Unload Appointment Unscheduled Move Completed	Appointment State Change Factory State Change (AMHS)	The LSA will shrink the load appointment to the specified time. The LSA will shrink the unload appointment to the specified time. If the current location of the lot is a machine port, then the system will cancel all appointments except the lot appointment. The lot appointment will only be cancelled if the appointment was for a different machine. If the appointment was for a different machine, the LSA will cancel all appointments and wait for the MSA to invoke override scheduling. Otherwise, the system will determine how long it will take for the lot to get back to the next processing appointment destination. If the lot can still make its processing start time, then the system will reschedule the appropriate move appointments. If the lot is unable to make the start time, it will cancel all move, load, unload, and lot appointments and will initiate scheduling.
55		
60		
65 Update Commitment	Appointment State Change	The LSA will update the lot appointment commitment window

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TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
Window For Lot Appointment		appropriately. The commitment window represents the lots earliest start time and latest delivery time for a given appointment. The commitment window is updated if an appointment is processing late and the new end time exceeds the latest delivery time of the appointment.
Update Load Time For Load Appointment	Appointment State Change	The LSA will update the load start time and remaining load time appropriately on the load appointment.
Wrong Move Completed	Appointment State Change	If the current location of the lot is a machine port, then the system will cancel all appointments except for the lot appointment. The lot appointment will only be cancelled if the appointment was for a different machine. If the appointment was for a different machine, the LSA will cancel all appointments and wait for the MSA to invoke override scheduling. Otherwise, the system will determine how long it will take for the lot to get back to the next processing appointment destination. If the lot can still make its original processing start time, then the system will reschedule the appropriate move appointments. If the lot is unable to make the start time, it will cancel all move, load, unload, and lot appointments and will initiate scheduling.
Lot Due Date Change	Factory State Change (MES)	If the lot has a processing appointment active, cancel appointments after either current appointment or following unload appointment (if present). If the appointment is in "near complete" status and the next process operation is not a control operation or there is no next operation in the process, schedule a move appointment after the current lot processing appointment. Otherwise, attempt to schedule the next process operation. If the lot has a move appointment active and the move is to a machine port destination, cancel appointments after the following load appointment (if present) and following lot processing appointment. Otherwise, cancel all appointments after the move appointment and reschedule the current process operation. If the lot has a feeder appointment active, cancel all appointments after the feeder appointment and reschedule the next process operation. If the lot has a load appointment active, cancel appointments after the following lot appointment or load appointment (if present.) If the lot has an unload appointment active, cancel appointments after the current time. If the next operation is not a control operation or there are no more operations, schedule a move appointment after the unload appointment. Reschedule for the next process operation. If no appointments are active, cancel all future appointments and reschedule current process operation.
Lot put on Hold	Factory State Change (MES)	If lot is processing, cancel appointment after post move appointment. If lot is moving to control machine port, cancel all appointments after the move and

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TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
5		schedule a move to the nearest stocker as soon as the lot arrives at the machine port. If unload appointment is processing, cancel all appointments after and schedule post move. If feeder appointment is processing, shrinks and aborts the appointment and then cancels all appointments after feeder appointment. If load appointment is processing, it cancels all appointments after except for the unload appointment. It will then schedule a post move appointment. If the lot has a processing appointment active, and it is in a status of processing or near complete, it is allowed to complete. If the next appointment is an unload appointment, all subsequent appointments are cancelled and a move is scheduled after the unload. If the next appointment is a move appointment, it and subsequent appointments are cancelled and another move is scheduled. If there are no subsequent appointments, a move is scheduled after the processing appointment. If the lot appointment is active but not processing or complete, it is shrunk and aborted. If the next appointment is an unload appointment, subsequent appointments are cancelled and a move appointment is scheduled. If the next appointment is a move appointment, it is cancelled and another move appointment is scheduled. If there are no next appointments, a move appointment is scheduled. If the lot is in a feeder appointment, it is shrunk and aborted and all subsequent appointments cancelled. If the lot is in a load appointment and it is in a processing status, the subsequent lot processing appointment is cancelled. The following unload appointment is left and all subsequent appointments cancelled. A move appointment is scheduled after the unload appointment (both will later shift earlier in reaction to appointment changes initiated by the RSA). If the load appointment is not processing, it and subsequent appointments are cancelled and a move appointment is scheduled. If the lot is in an unload appointment, all subsequent appointments are cancelled and a move appointment is scheduled after the unload appointment. If the lot is in a move appointment and the move has started, all subsequent appointments are cancelled. If the move is to a machine port, a move is scheduled to subsequently transport the lot off the machine port. If the lot is on a move appointment that has not started, the move appointment is aborted and all subsequent appointments cancelled.
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40		
45		
50		
55		
60	Process Changed Factory State Change (MES)	If the lot has a processing appointment active, cancel appointments after either current appointment or following unload appointment (if present). If the appointment is in "near complete" status and the next process operation is not a control operation or there is no next operation in the process, schedule a move appointment after the current lot processing appointment. If the lot is processing, cancel appointment after post move appointment. If lot is moving to control machine port, cancel all appointments after the move and

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TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
Process Operation Changed	Factory State Change (MES)	<p>appointment is near complete and the next operation is a control operation, attempt to schedule the next process operation. If the lot has a move appointment active and the move is to a machine port destination, cancel appointments after the following load and unload appointments (if present) and following lot processing appointment. Otherwise, cancel all appointments after the move appointment and reschedule the current process operation. If the lot has a feeder appointment active, cancel all appointments after the feeder appointment and reschedule the next process operation as well as any preceding feeder appointments. If the lot has a load appointment active, cancel appointments after the following unload appointment. If the lot has an unload appointment active, cancel appointments after the current time. If the next operation is not a control operation or there are no more operations, schedule a move appointment after the unload appointment. Reschedule for the next process operation. If no appointments are active, cancel all future appointments and reschedule current process operation.</p> <p>The LSA will remove all non-active appointments. The LSA will then check to see if the new process operation is a control or feeder process operation. If the process operation is a feeder, then the agent will schedule the next process operation. If the process operation is a control and the agent doesn't have an appointment for this process operation, it will schedule this process operation. If the lot has a processing appointment active, cancel appointments after either current appointment or following unload appointment (if present). If the appointment is in "near complete" status and the next process operation is not a control operation or there is no next operation in the process, schedule a move appointment after the current lot processing appointment. If the appointment is near complete and the next operation is a control operation, attempt to schedule the next process operation. If the lot has a move appointment active and the move is to a machine port destination, cancel appointments after the following load and unload appointments (if present) and following lot processing appointment. Otherwise, cancel all appointments after the move appointment and reschedule the current process operation. If the lot has a feeder appointment active, cancel all appointments after the feeder appointment and reschedule the next process operation as well as preceding feeder appointments. If the lot has a load appointment active, cancel appointments after the following unload appointment. If the lot has an unload appointment active, cancel appointments after the current time. If</p>
5	Event	
10		
15	Wafer Count Decreased	Factory State Change (MES)
20	Wafer Count Increased	Factory State Change (MES)
25		
30	Lot Terminated	Factory State Change (MES)
35	Lot Moved In	Factory State Change (MES)
40	Lot Moved Out	Factory State Change
45		
50		
55	Experimental Request Form ("ERF") Status Change	Factory State Change (MES)
60		
65	Override Lot Appointment	Factory State Change

TABLE 3-continued

<u>Reactive Scheduling Activities for LSAs</u>		
Event	Event Type	Reactive Scheduling Activities
the next operation is not a control operation or there are no more operations, schedule a move appointment after the unload appointment. Reschedule for the next process operation. If no appointments are active, cancel all future appointments and reschedule current process operation.		
10		
15	Wafer Count Decreased	Factory State Change (MES)
20	Wafer Count Increased	Factory State Change (MES)
25		
30	Lot Terminated	Factory State Change (MES)
35	Lot Moved In	Factory State Change (MES)
40	Lot Moved Out	Factory State Change
45		
50		
55	Experimental Request Form ("ERF") Status Change	Factory State Change (MES)
60		
65	Override Lot Appointment	Factory State Change

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TABLE 3-continued

Reactive Scheduling Activities for LSAs		
Event	Event Type	Reactive Scheduling Activities
Machine Advertises a Time Slot	Appointment State Change	LSA will determine if it can improve its processing appointment for the operation at the new time slot. If so, then the LSA cancel the appointment and publishes a submit bid message in attempt to reschedule the appointment for the advertised time slot.

TABLE 4

Reactive Scheduling Activities for PM Scheduling Agents		
Event	Event Type	Reactive Scheduling Activities
PM/Qual Appointment Cancelled	Appointment State Change	The PM appointment is canceled and rescheduled.
Expand PM/ Qual Appointment	Appointment State Change	The MSA initiates this change when the PM appointment is running long. The PMSA will react to this change by shifting all appointments to the right of the PM processing appointment being expanded. The appointments that cannot be shifted are canceled and rescheduled. It will then expand the PM appointment to the specified time.
Make PM/ Qual Appointment Aborted	Appointment State Change	The MSA initiates this change when the processing of the PM has been interrupted. The MSA will change the status of the appointment to aborted. The PMSA will reschedule the appointment.
Make PM/ Qual Appointment Processing	Appointment State Change	The MSA initiates this change when the MSA learns the PM has started. The MSA will change appointment to a processing status.
Make PM/ Qual Appointment Completed	Appointment State Change	The MSA initiates this change when the PM has completed processing and may shrink the appointment if appropriate. The PMSA will notify the processing agent, change the status to completed, and update the last occurrence of the PM with the current wafer count on the machine or current time.
Make PM Appointment Active PM/ Qual	Appointment State Change	The MSA initiates this change when it is time for the following Qual to start. The PMSA will change the status of the appointment to "active".
Make PM Appointment Processing PM/Qual	Appointment State Change	The MSA initiates this change when it receives a Factory State Change indicating the Qual portion of the PM appointment has started. The PMSA will change the status of the appointment to processing PM/Qual.
Shift PM/ Qual Appointment Left	Appointment State Change	The PMSA will try to move the PM appointment to the left. If it is unable to shift left, the system will cancel the appointment and reschedule it.
Shift PM/ Qual Appointment Right	Appointment State Change	The PMSA will try to move the PM appointment to the right. If it is unable to shift right, the system will cancel the appointment and reschedule it.
Shrink PM/ Qual Appointment	Appointment State Change	The PMSA will shrink the PM appointment to the specified time.
Update Commitment Window For PM/Qual Appointment	Appointment State Change	The PM appointment commitment window is updated. The commitment window represents the PMs earliest start time and latest delivery time for a given appointment.
Override PM/Qual Appointment	Appointment State Change	The PM appointment is cancelled within the calendar if it exist. It will then create a bid request and appointment change listener and return it to the MSA.

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TABLE 4-continued

Reactive Scheduling Activities for PM Scheduling Agents			
Event	Event Type	Reactive Scheduling Activities	
5		This is in response to an unscheduled PM being started.	
10	MES Machine Event Detected	Factory State Change	The PMSA will appropriately update the number of occurrences of the event within any PM or Qual that depends on this event. It will then schedule any PMs or Quals triggered by the event occurrence what are not currently scheduled on its calendar.
15	Lot Processing Completed on Machine	Factory State Change	The PMSA will reevaluate the commitment windows for all PMs or Quals that are scheduled based on a count of material processed. If the commitment window is invalid, the PMSA will either update the commitment window if the PM or Qual is scheduled within the new window, or it will cancel the existing appointment and reschedule within the new window. It will also schedule any PMs or Quals based on a count of material processed that have reached their trigger point and have not been schedule previously.
20			The PMSA will schedule any time-based PM or Qual that has reached its trigger point and was not previously scheduled.
25	Alarm Fired	Alarm Event	
30			
Reactive Scheduling Activities for Resource Scheduling Agents			
Event	Event Type	Reactive Scheduling Activities	
35	Appointment Start Time Alarm Fired for Load (Unload) Appointment	Alarm Event	This alarm indicates that the scheduled start time of the specified load (unload) appointment has arrived. The resource appointment scheduler will make the appointment active if it is not active. It will also create an appointment end time alarm if needed. The resource appointment scheduler will inform the processing agent to start processing the appointment.
40			
45	Appointment Start Time Alarm Fired for Discharge Appointment	Alarm Event	This alarm indicates that the scheduled start time of the specified discharge appointment has arrived. The resource appointment scheduler will make the appointment active if it is not active. It will also create an appointment end time alarm if needed. The resource appointment scheduler will inform the processing agent to start processing the appointment.
50			
55	Appointment End Time Alarm Fired for Load (Unload) Appointment	Alarm Event	This alarm indicates that the scheduled end time of the specified load (unload) appointment has arrived. The resource appointment scheduler will expand the appointment with a percentage (e.g., 25%) of the originally scheduled duration until a maximum expansion percentage has been reached (e.g., 175%). Before expanding the appointment, the subsequent booked appointments may be shifted later in time. A new end time alarm is then set for the expanded load (unload) appointment.
60			
65	Appointment End Time Alarm Fired for Charge Appointment	Alarm Event	This alarm indicates that the scheduled end time of the specified charge appointment has arrived. The resource appointment scheduler

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TABLE 5-continued

Reactive Scheduling Activities for Resource Scheduling Agents		
Event	Event Type	Reactive Scheduling Activities
Machine Batch Appointment Changes Its Status to Active	Appointment State Change	<p>will expand the appointment with a percentage (i.e., 25%) of the originally scheduled duration until a maximum expansion percentage has been reached (i.e., 175%). Before expanding the appointment, the subsequent booked appointments may be shifted later in time. A new end time alarm is then set for the expanded charge appointment.</p>
Machine Batch Appointment Changes Its State to Processing	Appointment State Change	The MSA initiates this change when the start time for the corresponding machine batch appointment has arrived. The RSA will change the corresponding appointment status of the current charge appointment to active, and a new end time alarm is set for the activated charge appointment.
Machine Batch Appointment Changes Its State to Completed	Appointment State Change	The MSA initiates this change when the machine batch appointment was actually started. The charge appointment will still have the active status.
Lot Load (Unload) Appointment Shifted to Later Time	Appointment State Change	The LSA initiates this change when a lot load appointment was shifted to a later time. The RSA will rearrange its corresponding load appointments, and shift other appointments on its calendar if necessary. If the appointment has a start time alarm, the alarm update will be performed.
Machine Batch Appointment Shifted Right to Later Time	Appointment State Change	The MSA initiates this change or responding the change from the lot scheduling calendar when a machine batch appointment was shifted to later time. The RSA will shift the corresponding charge and discharge appointment to later time. Other appointments on its calendar may also get shifted.
Machine Batch Appointment Shrunk	Appointment State Change	The MSA initiates this change when a machine batch appointment was shrunk. If the discharge appointment is not activated, the RSA will shift the corresponding discharge appointment to earlier time, otherwise it will shrink the discharge appointment. The start time alarm or end time alarm for the discharge appointment may need to be updated.
Machine Batch Appointment Expanded	Appointment State Change	The MSA initiates this change when a machine batch appointment was expanded. If the discharge appointment is not activated, the RSA will shift the corresponding discharge appointment to later time, otherwise it will expand the discharge appointment. The start time alarm or end time alarm for the discharge appointment may need to be updated.
Load Start	Factory State Change (EI)	The equipment interface ("EI") notifies the RSA that a load has started. The RSA reacts depending on whether the lots that were loaded were expected or unexpected. If all the lot are expected, but loading order is different from the appointments on

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TABLE 5-continued

Reactive Scheduling Activities for Resource Scheduling Agents		
Event	Event Type	Reactive Scheduling Activities
10 Carrier Arrived	Factory State Change	the calendar, the RSA will rearrange its load appointment and their participants.
15 Load Update	Factory State Change	The EI notifies the RSA that a carrier has arrived. If it carries the expected lot, the RSA will change the corresponding resource load lot appointment state to the ready status.
20		Upon notification by the EI, if the corresponding load appointment is not the first one in the batch job, the RSA will first shrink the previous load appointment, and pull the follow-up load appointment to earlier start time, the appointment state of the previous load appointment will be changed to the completed status. The end time alarm for the previous load appointment will be cancelled. The PMSA will change the next load appointments status to active.
25 Load Completed	Factory State Change	Upon notification by the EI that a load has completed, the RSA will shrink the corresponding load appointment, cancel the end time alarm and change the appointment state of the last load appointment to the completed status.
30 Charge Started	EI Event	Upon notification from the EI that charging has started, the RSA will change the charge appointment state to the processing status.
35 Charge Completed	EI Event	Upon notification from the EI that a charge is complete, the RSA will shrink the charge appointment, cancel the end time alarm, and change the charge appointment state to the completed status. If there are some follow-up unload appointments, it will pull the unload appointments to earlier start time, and start the unload appointment.
40 Discharge Started	EI Event	Upon notification from the EI that a discharge has started, the RSA will change the discharge appointment state to the processing status.
45 Unload Started	EI Event	Upon notification from the EI that unloading has started, the RSA will change the first unload appointment state to the processing status.
50 Unload Update	EI Event	Upon notification from the EI, an unload appointment is updated. If the corresponding unload appointment is not the last one in the unload start event, the RSA will shrink the corresponding unload appointment, cancel its end time alarm and change its status to the completed status.
55		The RSA will then pull the next unload appointment to earlier time and start processing the next unload appointment. If the corresponding unload appointment is the last one in the unload start event, the RSA will wait for unload completed event.
60 Unload Completed	EI Event	Upon notification from the EI that an unload has completed, the RSA will shrink the unload appointment, cancel its end time alarm and change the appointment state to the completed status.
65 Unexpected Unload Started	EI Event	Upon notification from the EI that an unload has unexpectedly started (i.e., the next appointment is not an unload

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TABLE 5-continued

Reactive Scheduling Activities for Resource Scheduling Agents		
Event	Event Type	Reactive Scheduling Activities
Unexpected Load Started	EI Event	<p>appointment or the transfer sequence is different from the scheduled one) the RSA will change the scheduled unload appointments, and make the first one active. Overlapping appointment may get shifted to later time or cancelled.</p> <p>Upon notification from the EI that a load has unexpectedly started (i.e., the next appointment is not a load appointment or the transfer sequence is different from the scheduled one), if there is a lot in the list that is not one of the participant of the next charge appointment, the RSA passes a lot list and batch ID to a MSA for appropriate response. If all the lots are in the next charge appointment, but the transfer sequence is different from the schedule appointments, the RSA will reschedule the load appointments.</p>

Note that, as booked appointments are shifted, canceled, shrunk, expanded, and rescheduled, the changes can ripple through the process flow and, in particular, the calendars. Changes are instituted by a single software agent, but a changed appointment may be booked on multiple calendars. The changes must consequently be communicated to the other software agents so they can update their calendars respectively. This is true also of other types of events in the process flow.

In the illustrated embodiment, the invention is implemented using object oriented programming ("OOP") techniques, although the invention may be implemented using techniques that are not object oriented. The software agents 265 are implemented as objects and are intelligent, state aware, and are imbued with specific goals for which they autonomously initiate behaviors to achieve. Their behavior is relatively simple and is partially configurable through scripts and properties. The behavior is designed to achieve selected goals such as achieving an assigned lot due date, achieving a predefined level of quality, maximizing machine utilization, and scheduling opportunistic preventive maintenance. The helper class is a class of objects to which various objects that are software agents 265 delegate various responsibilities or that provide some useful service in the process flow 100. Publishers and listeners, mentioned above, are also helper class objects.

Thus, some portions of the detailed descriptions herein are presented in terms of a software implemented process involving symbolic representations of operations on data bits within a memory in a computing system or a computing device. These descriptions and representations are the means used by those in the art to most effectively convey the substance of their work to others skilled in the art. The process and operation require physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical, magnetic, or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

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It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantifies. Unless specifically stated or otherwise as 5 may be apparent, throughout the present disclosure, these descriptions refer to the action and processes of an electronic device, that manipulates and transforms data represented as physical (electronic, magnetic, or optical) quantities within some electronic device's storage into other data similarly 10 represented as physical quantities within the storage, or in transmission or display devices. Exemplary of the terms denoting such a description are, without limitation, the terms "processing," "computing," "calculating," "determining," "displaying," and the like.

15 Note that the software implemented aspects of the invention are typically encoded on some form of program storage medium or implemented over some type of transmission medium. The program storage medium may be magnetic (e.g., a floppy disk or a hard drive) or optical (e.g., a compact 20 disk read only memory, or "CD ROM"), and may be read only or random access. Similarly, the transmission medium may be twisted wire pairs, coaxial cable, optical fiber, or some other suitable transmission medium known to the art. The invention is not limited by these aspects of any given 25 implementation.

This concludes the detailed description. The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art 30 having the benefit of the teachings herein. Note that further variations not discussed may be employed in still other embodiments. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that 35 the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

What is claimed:

- 40 1. A method for scheduling in an automated manufacturing environment, comprising:
automatically detecting an occurrence of a predetermined event in an integrated, automated process flow;
automatically notifying a software scheduling agent of the occurrence; and
reactively scheduling an action from the software scheduling agent responsive to the detection of the predetermined event.
- 45 2. The method of claim 1, wherein automatically detecting the occurrence of the predetermined event includes detecting an unplanned event or an unexpected event.
- 50 3. The method of claim 1, wherein automatically detecting the occurrence of the predetermined event includes detecting an occurrence of an appointment state change.
- 55 4. The method of claim 3, wherein automatically detecting the appointment state change includes detecting at least one of an appointment cancellation, an appointment expansion, an appointment shrinking, an appointment abort, an appointment changing status, an appointment shift, an appointment override, an transport time update, a load time update, an unload time update, a lot joining a batch, a lot leaving a batch, canceling a lot from a batch, and a commitment window update.
- 60 5. The method of claim 1, wherein automatically detecting the predetermined event includes detecting at least one of an appointment cancellation, an appointment expansion, an appointment shrinking, an appointment abort, an appoint-

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ment becoming active, an appointment nearing completion, an appointment completing, an appointment shift, an appointment override, and a commitment window update; detection of a downtime occurrence; a machine becoming available; a PM/Qual being detected; a chamber going down; a chamber becoming available, a change in machine capabilities; a change in machine types; an addition of a process; an addition of a process operation; a lot arriving at a machine; a lot process changed, a lot placed on hold, a lot released from hold, a lot priority changed, a lot due date changed, a lot wafer count changed, a lot process operation changed, a lot departing a machine, an alarm firing for an appointment start time and an alarm firing for an appointment end time.

6. The method of claim 1, wherein automatically notifying the software scheduling agent of the occurrence includes:

sending an indication of the occurrence to a publisher; publishing the occurrence from the publisher to a subscribing listener; and

calling the software scheduling agent from the subscribing listener.

7. The method of claim 1, wherein reactively scheduling the action includes at least one of aborting a scheduled appointment in progress; canceling a scheduled appointment duration of a scheduled appointment; shrinking the duration of a scheduled appointment; shifting a scheduled appointment; adding new processing capabilities; deleting old processing capabilities; setting an alarm; canceling an alarm; and changing the status of an appointment.

8. The method of claim 1, further comprising proactively scheduling an appointment with which the predetermined event is associated.

9. The method of claim 8, wherein proactively scheduling the appointment includes proactively scheduling the appointment from the software scheduling agent.

10. The method of claim 1, wherein detecting the occurrence of the predetermined event includes detecting an occurrence of a factory state change.

11. The method of claim 10, wherein automatically detecting the factory state change includes detecting at least one of detection of a downtime occurrence; a machine becoming available; a PM/Qual being detected; a chamber going down; a chamber becoming available, a change in machine capabilities; a change in machine types; an addition of a process; an addition of a process operation; a lot arriving at a machine; a lot process changed, a lot placed on hold, a lot released from hold, a lot priority changed, a lot due date changed, a lot wafer count changed, a lot process operation changed, and a lot departing a machine.

12. The method of claim 1, wherein detecting the occurrence of the predetermined event includes detecting an occurrence of an alarm event.

13. The method of claim 12, wherein automatically detecting the alarm event includes detecting at least one of

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an alarm firing for an appointment start time and an alarm firing for an appointment end time.

14. An automated manufacturing environment, comprising:

an integrated, automated process flow; and
a computing system, including a plurality of software scheduling agents residing thereon, the software scheduling agents being capable of reactively scheduling appointments for activities in the process flow responsive to an automatic detection and notification of a plurality of predetermined events.

15. The automated manufacturing environment of claim 14, further comprising a plurality of publishers and subscribers capable of detecting an occurrence of one of the predetermined events in the process flow and notifying one of the software scheduling agent of the occurrence.

16. The automated manufacturing environment of claim 15, wherein the automatic detection of the predetermined event includes detecting an unplanned event or an unexpected event.

17. The automated manufacturing environment of claim 15, wherein the automatic detection of the predetermined event includes detecting an occurrence of an appointment state change.

18. The automated manufacturing environment of claim 15, wherein the automatic notification of the software scheduling agent of the occurrence includes:

sending an indication of the occurrence to a publisher; publishing the occurrence from the publisher to a subscribing listener; and

calling the software scheduling agent from the subscribing listener.

19. The automated manufacturing environment of claim 15, wherein reactively scheduling the action includes at least one of aborting a scheduled appointment in progress; canceling a scheduled appointment before it begins; scheduling a new appointment; starting a scheduled appointment; expanding the duration of a scheduled appointment; shrinking the duration of a scheduled appointment; shifting a scheduled appointment; adding new processing capabilities; deleting old processing capabilities; setting an alarm; canceling an alarm; and changing the status of an appointment.

20. The automated manufacturing environment of claim 15, further comprising proactively scheduling an appointment with which the predetermined event is associated.

21. The automated manufacturing environment of claim 15, wherein the automatic detection of the predetermined event includes detecting an occurrence of a factory state change.

22. The automated manufacturing environment of claim 15, wherein the automatic detection of the predetermined event includes detecting an alarm event.

* * * * *